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# Complete IF Receiver Has 16-Bit, 130Mps ADC, Fixed-Gain Amplifier and Antialias Filter in 11.25mm × 11.25mm $\mu$ Module Package

by Todd Nelson

## Introduction

In the design of high speed receivers for communications, test or instrumentation equipment, several specialized disciplines converge in one place—the analog-to-digital converter (ADC). Unfortunately, the ADC is not a simple black box where an RF designer applies the signal and a digital designer retrieves the accurate output. Careful design of the signal conditioning circuitry to drive the ADC is critical. Something as seemingly straightforward as board layout can degrade the downstream signal by a few precious decibels. The problem is that the disciplines required for the engineering on either side of the ADC, namely RF/IF design and digital design, do not include mastery of the art of ADC interface design. Someone has to put in the effort to properly drive the ADC. But who? Instead of adding more work to either designer's plate, what if the ADC were really a black box, already loaded with integrated signal conditioning components in an optimized layout? Now, *that* would be a better solution.

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***The LTM9001 is built using Linear Technology's  $\mu$ Module technology to create an IC form factor System-in-a-Package (SiP) that includes a high speed 16-bit ADC, antialiasing filter and a low noise, differential amplifier with fixed gain. It can digitize wide dynamic range signals with an intermediate frequency (IF) range up to 300MHz.***

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The LTM9001 is exactly that black box. It is built using Linear Technology's  $\mu$ Module™ technology to create an IC form factor System-in-a-Package (SiP) that includes a high speed 16-bit ADC, antialiasing filter and a low noise, differential amplifier with fixed gain. It can digitize wide dynamic range

*continued on page 3*



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LTM9001, continued from page 1

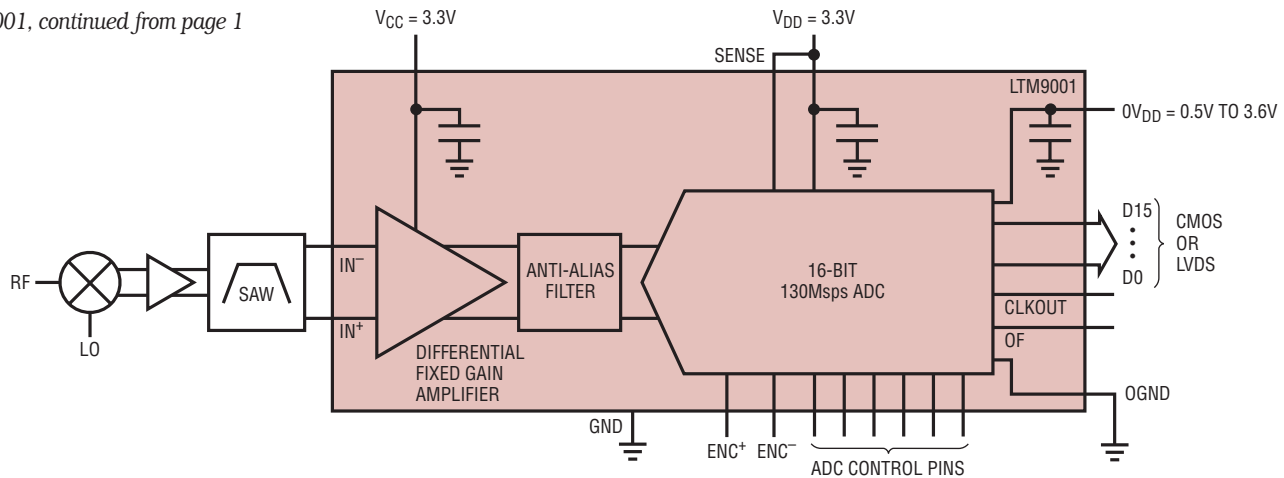


Figure 1. A typical application and simplified block diagram of the LTM9001

signals with an intermediate frequency (IF) range up to 300MHz. Figure 1 shows a typical application.

How is a  $\mu$ Module component different than a traditional IC? The  $\mu$ Module construction allows the LTM9001 to mix standard ADC and amplifier components regardless of their process technology and match them with passive components for a particular application. The result is a high performance product with no process technology compromises and the potential for semi-custom adaptations.

### What's Inside?

The  $\mu$ Module receiver consists of wire-bonded die, packaged components and passives mounted on a high performance, 4-layer, Bismaleimide-Triazine (BT) substrate. BT is similar to other laminate substrates such as FR4 but has superior stiffness and a lower coefficient of thermal expansion.

In time, several different versions of the LTM9001 will be available. The LTM9001-AA, as the first release, is configured with a 16-bit, 130Msps ADC. The amplifier gain is 20dB with an input impedance of 200 $\Omega$  and an input range of  $\pm 250$ mV. The matching network is designed to optimize the interface between the amplifier outputs and the ADC inputs under these conditions. Additionally, there is a second order bandpass filter designed for 162.5MHz,  $\pm 25$ MHz to prevent aliasing and to limit the noise from the amplifier.

Extracting the full performance from 16-bit, high speed ADCs requires careful layout as well as good circuit design. The substrate design carefully shields sensitive analog traces, maximizes thermal conduction through multiple ground pads and minimizes coupled noise by including bypass capacitors inside the module and close to the ADC. A common problem with traditional ADC board layouts is long traces from the bypass capacitors to the ADC. The bare die construction with internal bypass capacitors provides the closest possible decoupling and eliminates the need for external bypass capacitors.

The passive filter network implements an antialias filter and matches the amplifier outputs to the ADC inputs. Most communications receiver applications utilize a highly selective filter between the mixer and the ADC driver. The antialias filter between the ADC driver and the ADC inputs limits the wideband amplifier noise and helps preserve the high SNR of the ADC. Printed circuit board (PCB) layout has a significant impact on the performance even if the circuit topology and component values are correct. The signal paths must be symmetric and isolated from the clock inputs and digital outputs.

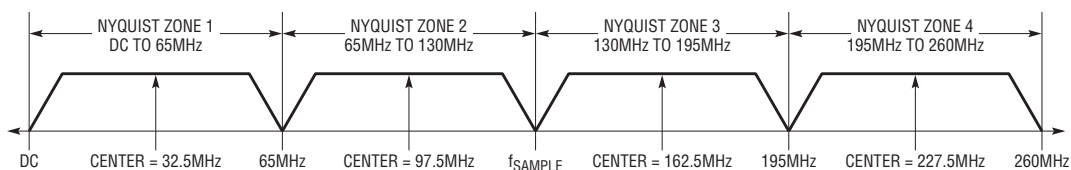
The low noise, low distortion amplifier stage provides gain without adding significant noise or distortion to the signal. Despite the low noise of the amplifier, the noise is multiplied by the same gain as the amplifier, so higher

gain unavoidably adds noise to the system. However, the input range of the amplifier is proportionately smaller thanks to the gain and this smaller input range allows for lower distortion from the preceding components. The amplifier inputs present a resistive 200 $\Omega$  differential input impedance which is simple to match to most common, high speed, single-ended or differential signal paths. This presents a more straightforward interface than a switched-capacitor ADC and simplifies the connection to the final stage of the RF signal chain.

### Why 162.5MHz?

The ADC inside the LTM9001 has a full power bandwidth of 700MHz and the amplifier is suitable for input frequencies up to 300MHz, so why was 162.5MHz chosen for this first version? Nyquist theory tells us that the minimum sample rate for a given input frequency is twice that frequency. Working backwards, an ADC sampling at 130Msps can capture a frequency range up to 65MHz wide. Undersampling allows us to move that frequency range. Hence the first Nyquist zone is DC – 65MHz, the second is 65MHz to 130MHz, the third is 130MHz to 195MHz, and so on, see Figure 2.

The LTM9001-AA is intended for instrumentation applications. In such applications, the linearity and dynamic range requirements are extremely high. Traditional instruments utilize preselectors and multiple down-con-



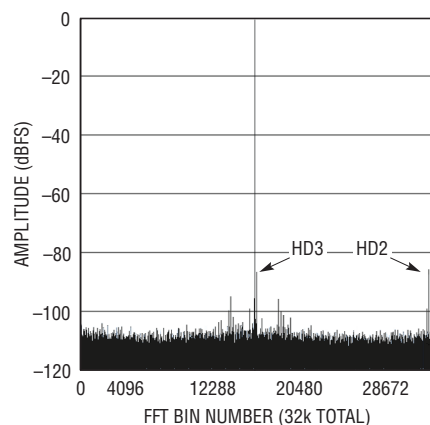
**Figure 2. Nyquist zones for 130MHz sample rate**

version stages to place the band of interest at DC. With the advent of high performance ADCs capable of undersampling, modern instruments are able to eliminate the final down-conversion stage without sacrificing performance. The LTM9001-AA configuration selects the third Nyquist zone with the bandpass filter set squarely in the middle of the zone.

## More than Just a Buffered ADC

The sample-and-hold front end of discrete ADCs presents a complex charge/discharge profile to the drive circuitry. Ideally, the input circuitry should be fast enough to fully charge the sampling capacitor during the sampling period (half of the clock period), but this is not always possible and the incomplete settling may degrade the SNR and SFDR. Some manufacturers promote a “buffered” ADC as a solution but this falls short of addressing the system-level solution since a low distortion amplifier is still required to provide the full-scale input to the ADC.

From the system view, the ADC follows the RF and IF portions of the receiver chain and converts the signal to a digital format. The signal comes from the antenna with very little power.



**Figure 3. An FFT of the LTM9001 at 160MHz input frequency with the randomizer on**

The signal must be filtered and amplified through each stage. Amplification (gain) increases the total noise and reduces the headroom, which generally causes more distortion. The added distortion may be addressed with a higher supply voltage or a higher power amplifier, neither of which is preferable. Therefore, from the system-level point of view, an ADC with a small input range is better.

The LTM9001 meets these system-level criteria. The resistive amplifier inputs are easily matched and it has an input range of  $\pm 250\text{mV}$ , enabling the use of low OIP3 components or higher loss SAW filters. The noise of the amplifier is low enough that the SNR of the LTM9001 is good despite the high gain (see Figure 3).

## Working with a $\mu$ Module Receiver


The LTM9001 uses a land grid array (LGA), which provides higher pin density than dual in-line or quad packages and better thermal conduction than BGA packages. The high integration of the LTM9001 makes the PCB board layout simple. The multilayer substrate allows greater flexibility in pin placement on the package relative to pin placement on the die. The LTM9001 has been optimized for a flow-through layout so that the interaction between inputs, clock and digital outputs is minimized. The analog and clock inputs are surrounded by ground pads and a continuous row of ground pads further separate the analog and digital signal lines. However, to optimize its electrical and thermal performance, some layout considerations are still necessary. See the actual evaluation board in Figure 4.

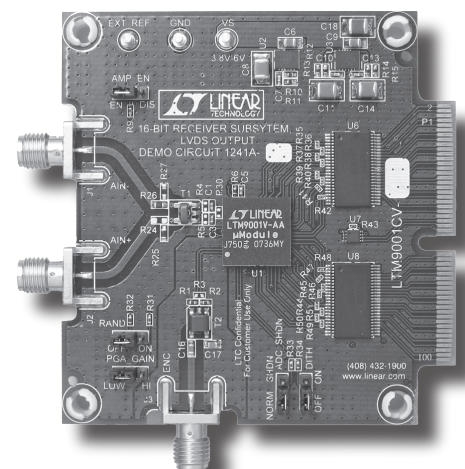
Use large PCB copper areas for ground. This helps to dissipate heat through the board and also helps to shield sensitive on-board analog signals. Common ground (GND) and

output ground (OGND) are electrically isolated on the LTM9001, but for most digital output configurations should be connected on the PCB underneath the part to provide a common return path.

Use multiple ground vias. Using as many vias as possible helps to improve the thermal performance of the board and creates necessary barriers separating analog and digital traces on the board at high frequencies. Take care to separate analog and digital traces as much as possible, using vias to create high frequency barriers. This reduces digital feedback that can reduce the signal-to-noise ratio (SNR) and dynamic range of the LTM9001.

## Conclusion

$\mu$ Module technology, introduced first by Linear Technology for DC/DC converters, now brings the advantages of small size, higher integration and ease of use for high speed ADC applications. By integrating fine-line CMOS and SiGe components with appropriate passive networks, the challenging task of matching a fixed gain amplifier to a high speed ADC is done. All is reduced to an easy-to-use black box: the LTM9001. 



**Figure 4. An evaluation board shows the small overall circuit. Note that no external components are required.**